PROGRESS REPORT

PR 91570-510-7

For the Period of January 1, 1964, through January 31, 1964

DEVELOPMENT OF A HYDROGEN-OXYGEN SPACE POWER SUPPLY SYSTEM

NASA Contract NAS 3-2787

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INTRODUCTION

This report is issued to comply with the requirements of NASA Contract, NAS 3-2787, and to report the work accomplished during the period January 1 through January 31, 1964. The objectives of this program are to conduct engineering studies, design, fabrication, and test work culminating in the design of an auxiliary power generation unit.

This contract, NAS 3-2787, is a continuation of NASA Contract NAS 3-2550.

PROGRAM SCHEDULE

The program schedule shown in Fig. 1 has been revised to reflect changes in the program plans resulting from a technical review meeting between NASA and Vickers Inc. on January 16 and 17, 1964. Component development and endurance testing will be extended through July, 1964. Flight system design work will continue to be deferred until additional development and endurance testing have been accomplished.

FLIGHT TYPE POWER SYSTEM DESIGN

No work was scheduled during this reporting period on the flight type power system design because of technical direction from the NASA Technical Program Manager.

PROTOTYPE COMPONENT DEVELOPMENT

Engine

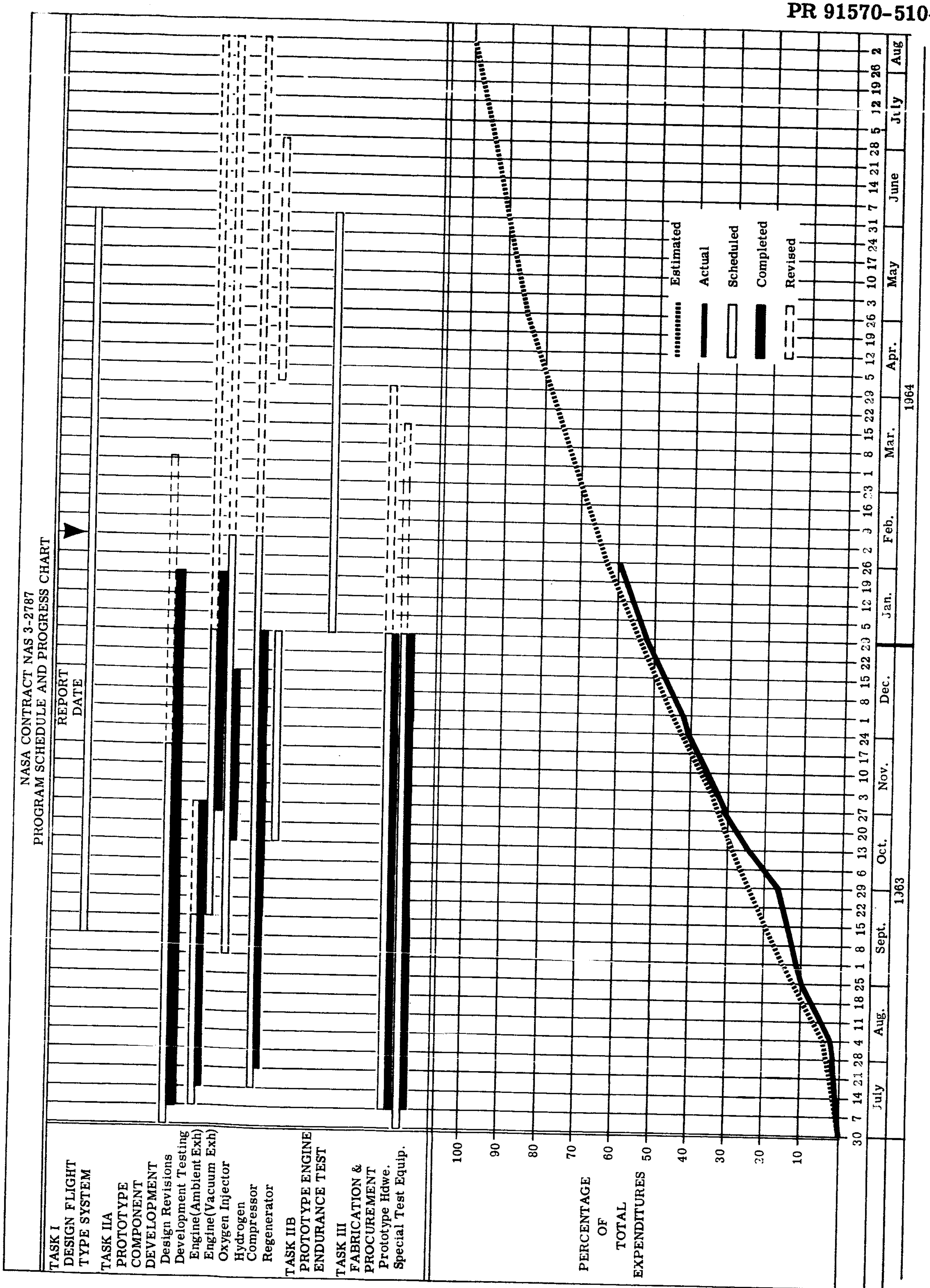


Fig. 1 - Program Schedule

Design and Fabrication

The following design and fabrication was accomplished during this reporting period.

1. Fabrication of two additional hydrogen valves of the redesigned configuration (shown in Fig. 2 of PR 91570-510-2) is completed. The new valves have heat shields to protect the valve guide from direct impingement of hot hydrogen.

2. All drawings for the new piston and cylinder design (shown in Fig. 3, PR 915701510-5) are released, and hardware is being fabricated.

3. Twenty-four (24) sets of three piece piston rings have been fabricated.

4. Three oxygen injector poppet blanks without flats are being fabricated for application of Calcium Fluoride to the guide bearing area by NASA.

5. The present piston and dome configuration is being reworked to reduce the possibility of leakage through the piston. This is an interim design modification which will be used until the fabrication of the new piston and cylinder design is complete.

Assembly

The second buildup of Engine No. I was removed from the test stand on January 17 after 6.2 hours of hot running and 8.2 hours of cold running. Testing was stopped because of failure of the piston dome securing screw. Failure of the screw allowed the piston dome to jam between the piston body and the cylinder head. Damage to the following parts was observed during teardown:

1. The metallic "O" ring seal between piston dome and piston.

2. The piston dome is shown in Figs. 2 and 3.

3. The piston body is shown in Fig. 4. The sealing surface of the piston body was cleaned by grinding away 0.002 inches.

4. The surface of the cooled cylinder head insert was nicked as shown in Fig. 5. The nicks were removed by reworking the head for a 7% clearance volume.

5. The crankshaft spline was twisted as shown in Fig. 6.

6. The hub, which mates with the crankshaft spline was damaged.

7. The upper cylinder bore was marked from the piston dome; however, damage was superficial and was corrected by light honing.

The following parts were Magnifluxed: cylinder, timing gears (2), camshaft, adapter, hub, stud bolts (4), piston, piston pin, upper crankcase, lower crankcase, and the cylinder head ring. Three small cracks were observed on the piston body. The cylinder head insert was Magnifluxed after rework, no cracks were observed.

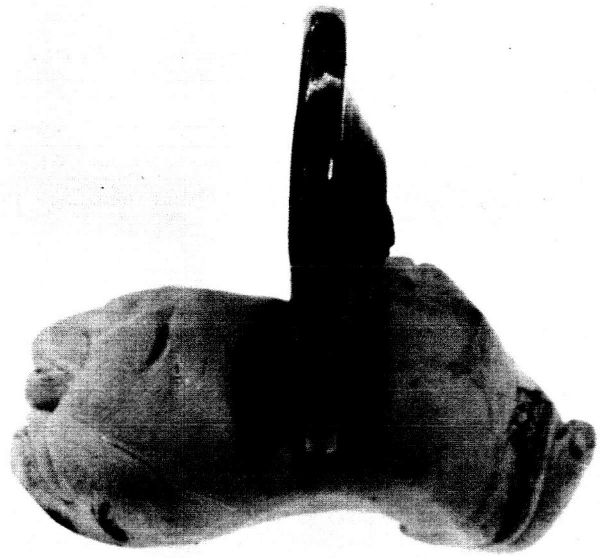


Fig. 2 - Piston Dome - Side View

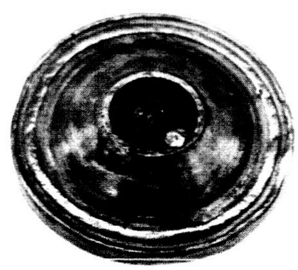


Fig. 3 - Piston Dome - Bottom View

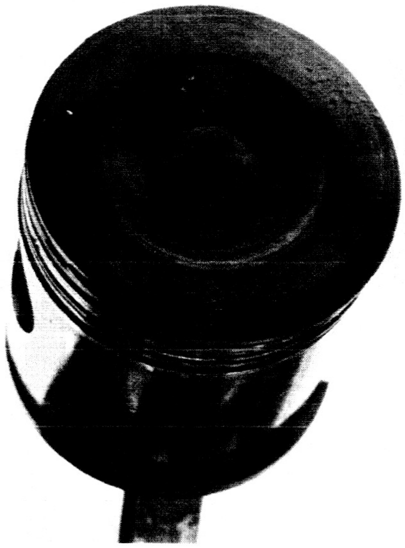


Fig. 4 - Damaged Seal Surface of Piston

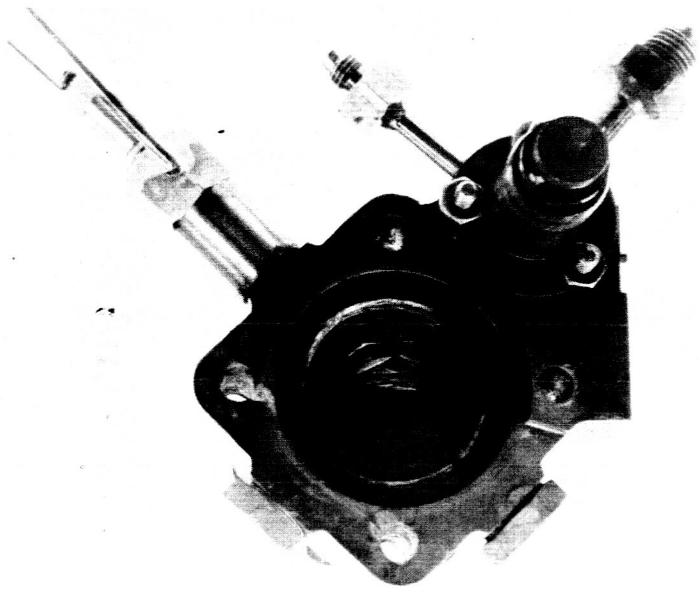


Fig. 5 - Damaged Surface of Cooled Cylinder Head Insert

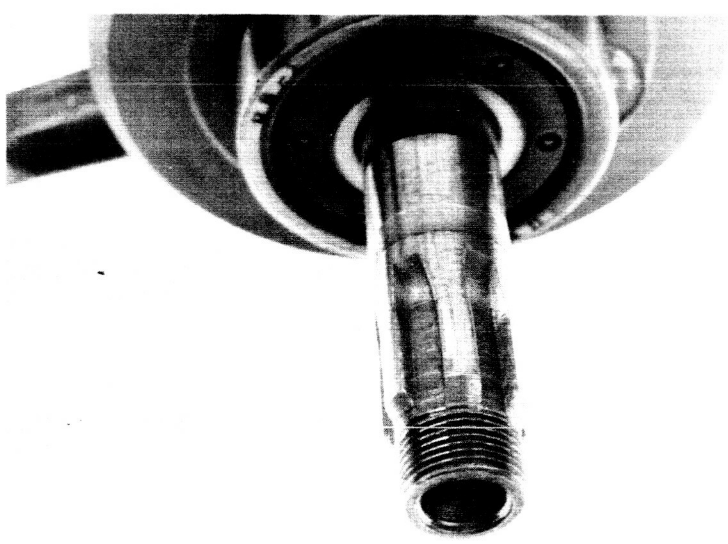


Fig. 6 - Twisted Crankshaft Spline

The No. 3 buildup of Engine No. I was made using an alternate piston body, the reworked cooled cylinder head, and the following new parts; hub, crankshaft and rod assembly, piston dome, dome seal ring, dome securing screw, and new 3-piece compression rings.

50 in-lb of torque was used to secure the dome screw as opposed to 80 in-lbs which was used for buildup No. 2.

The piston was removed from buildup No. 3 after two hours of cold run in and 30 minutes of hot running after a leak developed between the dome and piston.

Performance Testing

Performance test data accumulated during the month of January, 1964, are given in Tables I and II. Engine valve timings and other operating conditions are given in Table III.

The engine was operated for 6.3 hot hours and motored under cold gas or hydraulic power for 8.2 hours.

All performance testing was done with the second buildup of Engine No. 1, incorporating inward opening hydrogen valves. Hydrogen pressure was kept to a maximum of 300 psi to simulate operation from supercritical tankage. Higher hydrogen pressures would require stiffer hydrogen valve springs with resulting higher friction. Power level was varied by adjusting admission and clearance volume. Most tests were run with a cooled cylinder head, to permit operation at high O/F ratios.

In the last column of Tables I and II is given the exhaust pressure in mm Hg absolute, measured at the engine exhaust manifold. Exhaust pressure was varied by throttling the vacuum pump to the desired level. Two or three levels of exhaust pressure were used at each setting,

TABLE I

ENGINE PERFORMANCE DATA

Entry	Time Date	Time Hour	Oper. Cond. No.	H_2 Inlet Temp °F	H_2 Inlet Press psig	O_2 Inlet Press psig	Speed rpm	BMEP psi	Power HP	BSPC lb/hp-hr	O/F lb/lb	% Heat Rejected	Vacuum mm Hg
1	1-4-64	11:10	1	490	300	1110	3000	85	1.74	2.49	1.78	85	377
2	1-4-64	11:15	1	490	300	1120	4360	61	1.98	2.65	1.43	96	430
3	1-4-64	11:22	1	140	300	1125	4320	74	2.21	2.64	1.58	91	460
4	1-4-64	11:27	1	120	300	1120	3010	105	2.17	2.45	1.76	82	412
5	1-4-64	11:30	1	115	300	1125	3070	116	2.39	2.38	1.61	72	164
6	1-7-64	3:50	2	90	300	700	3040	103	2.14	2.56	1.33	80	757
7	1-7-64	3:57	2	90	300	1000	3000	122	2.50	2.44	1.79	71	757
8	1-7-64	4:00	2	100	300	1000	3020	149	3.08	2.14	1.55	67	330
9	1-7-64	4:06	2	100	300	1000	4030	123	3.42	2.10	1.31	55	355
10	1-7-64	4:15	2	100	300	1100	3000	160	3.30	2.05	1.56	62	233
11	1-7-64	4:21	2	105	300	1100	3000	163	3.35	2.04	1.54	58	150
12	1-7-64	4:25	2	110	300	1100	4010	144	3.96	1.92	1.32	48	178
13	1-7-64	4:30	2	110	300	1100	3020	167	3.47	1.95	1.57	56	110
14	1-8-64	3:30	3	100	300	1000	3020	117	2.42	2.26	1.75	75	273
15	1-8-64	3:34	3	100	300	1000	4020	101	2.79	2.11	1.50	61	310
16	1-8-64	3:38	3	100	300	1000	3020	119	2.48	2.20	1.75	69	277
17	1-8-64	3:42	3	100	300	1000	3020	128	2.66	2.13	1.66	64	122
18	1-8-64	3:47	3	110	300	1000	4020	111	3.06	2.05	1.45	56	140
19	1-8-64	3:58	3	440	300	1000	4040	96	2.67	2.04	1.56	64	241
20	1-8-64	4:01	3	460	300	1000	2990	105	2.15	2.30	1.95	79	210
21	1-8-64	4:07	3	460	300	1000	3020	105	2.17	2.25	1.90	76	265
22	1-8-64	4:13	3	130	300	1000	3000	122	2.52	2.16	1.74	63	150
23	1-9-64	2:44	4	95	300	1000	3010	83	1.72	2.67	1.88	105	250
24	1-9-64	2:48	4	100	300	1000	4060	81	2.26	2.22	1.65	76	290
25	1-9-64	2:53	4	100	300	1000	4040	85	2.36	2.16	1.66	73	290
26	1-9-64	2:57	4	100	300	1000	3010	89	1.84	2.49	2.03	90	250
27	1-9-64	3:06	4	105	300	1000	3000	92	1.88	2.55	2.03	92	175
28	1-9-64	3:16	4	700	300	1000	3040	80	1.68	2.51	2.18	95	155

TABLE II

ENGINE PERFORMANCE DATA

Entry	Time Date	Time Hour	Oper. Cond. No.	H_2 Inlet Temp °F	H_2 Inlet Press psig	O_2 Inlet Press psig	Speed rpm	BMEP psi	Power HP	BSPC lb/hp-hr	O/F lb/lb	% Heat Rejected	Vacuum mm Hg
1	1-11-64	2:35	5	85	300	400	3000	81	1.67	2.46	1.42	95	764
2	1-11-64	2:40	5	90	300	400	4060	71	1.98	2.29	1.00	66	763
3	1-11-64	2:50	5	100	300	400	3010	104	2.14	2.03	1.08	56	437
4	1-11-64	2:58	5	105	300	500	4060	101	2.81	1.88	1.06	49	468
5	1-11-64	3:05	5	110	300	600	4040	108	2.99	1.97	1.16	54	250
6	1-11-64	3:12	5	100	300	540	3000	121	2.49	1.96	1.33	64	212
7	1-14-64	3:41	8	70	300	900	3000	85	1.77	2.73	1.73	121	760
8	1-14-64	3:45	8	85	300	900	4280	73	2.13	2.59	1.58	114	760
9	1-14-64	4:05	8	85	300	900	3000	89	1.83	2.60	1.84	112	760
10	1-16-64	2:44	8	425	300	1100	4080	99	2.76	2.02	1.29	86	303
11	1-16-64	2:49	8	360	300	1100	3070	102	2.14	2.49	1.79	188	255
12	1-17-64	3:39	9	80	300	900	3020	128	2.66	2.42	1.75	80	761
13	1-17-64	3:46	9	90	300	900	3000	165	3.40	2.16	1.79	71	305
14	1-17-64	3:49	9	95	300	900	4010	146	4.01	2.14	1.64	58	305
15	1-17-64	3:58	9	90	300	500	3010	146	3.03	2.14	1.47	50	277
16	1-17-64	4:05	9	95	300	500	3000	144	2.96	2.19	1.48	55	275
17	1-17-64	4:12	9	100	300	600	4000	138	3.79	2.03	1.29	46	315

TABLE III

ENGINE OPERATING CONDITIONS

1. Cooled head, 5% clearance volume, 0.045" injector orifice, four 3-piece piston rings. Timing: H_2 5° BTDC - 30° ATDC
   O_2 20° ATDC - 60° ATDC

2. Same as No. 1, except for timing: H_2 5° BTDC - 40° ATDC
   O_2 20° ATDC - 60° ATDC

3. Same as Nos. 1 and 2, except for timing: H_2 5° BTDC - 30° ATDC
   O_2 10° ATDC - 50° ATDC

4. Same as Nos. 1, 2, and 3, except for timing: H_2 5° BTDC - 20° ATDC
   O_2 0° (TDC) - 40° ATDC

5. Uncooled head, 8.5% clearance volume, 0.045" injector orifice, three 3-piece piston rings and one 1-piece high pressure piston ring in top groove, timing: H_2 5° BTDC - 30° ATDC
   O_2 10° ATDC - 50° ATDC

6. Cooled head, 5% clearance volume, timing: H_2 140° BTDC - 120° BTDC
   O_2 20° BTDC - 20° ATDC
   Otherwise same as No. 5.

7. Same as No. 6, except for timing: H_2 140° BTDC - 120° BTDC
   O_2 10° ATDC - 50° ATDC

8. Same as No. 6, but with timing: H_2 5° BTDC - 30° ATDC
   O_2 10° ATDC - 50° ATDC

9. Same as No. 6, but with 0.063" O_2 injector orifice, and timing:
   H_2 5° BTDC - 40° ATDC
   O_2 20° ATDC - 60° ATDC

varying between 100 and 500 mm mercury. (1 psia = 52 mm Hg). A back pressure of 50 mm Hg or less would result if the vacuum pump were fully open. However, misfiring has always occurred before this point is reached, making throttling necessary. In practice, the engine was allowed to stabilize at a back pressure around 300 mm Hg and data taken. Back pressure was then reduced to the lowest level possible without misfiring. Since less back pressure entails less recompression and permits greater hydrogen admission, BMEP was always at a maximum at the lowest exhaust pressure. See, for example, Entries 7, 8, 10, and 11 of Table I.

Misfiring is thought to be due to inadequate catalyst area for ignition when hot residual exhaust gas volume becomes very low. It appears to be more dependent on temperature than on mixture ratio. At a cylinder head temperature of less than 900°F it is very difficult to run with an exhaust pressure of less than 400 mm Hg without misfiring.

Pressure-time traces of test runs during the month of January are given in Figs. 7 through 23. A discussion of these tests follows.

Tests were run 4 January to determine the effects of very late oxygen admission on performance. It was felt that late admission might promote turbulence and better mixing at high O/F ratios. The results are given in Entries 1 through 5 of Table I and in Figs. 7 and 8. Power output was similar to the level usually observed at this hydrogen valve cutoff, (8% admission) and BSPC and heat rejection were somewhat high.

Four sets of three piece piston rings were used in this buildup. An examination of the rings on January 5 revealed that they were not fully seating at the top, so the engine was motored under hydraulic power for 8 hours of further breakin.

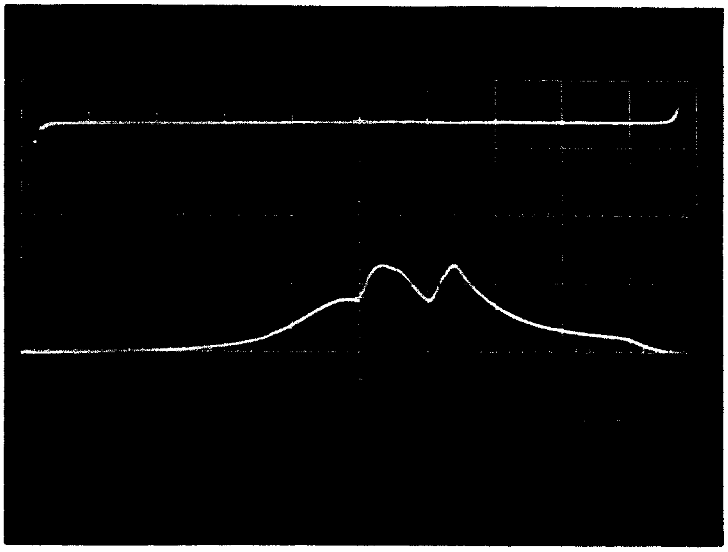


Fig. 7

1-4-64 11:22

Entry No. 3, Table I

H_2 Inlet Pressure = 300 psig

H_2 Inlet Temp. = 140°F

O_2 Inlet Pressure = 1125 psig

Vacuum = 460 mm Hg

Speed = 4320 rpm

Power = 2.21 HP

BSPC = 2.64 lb/hp-hr

BMEP = 74 psi

O/F = 1.58

% Heat Rejected = 91%

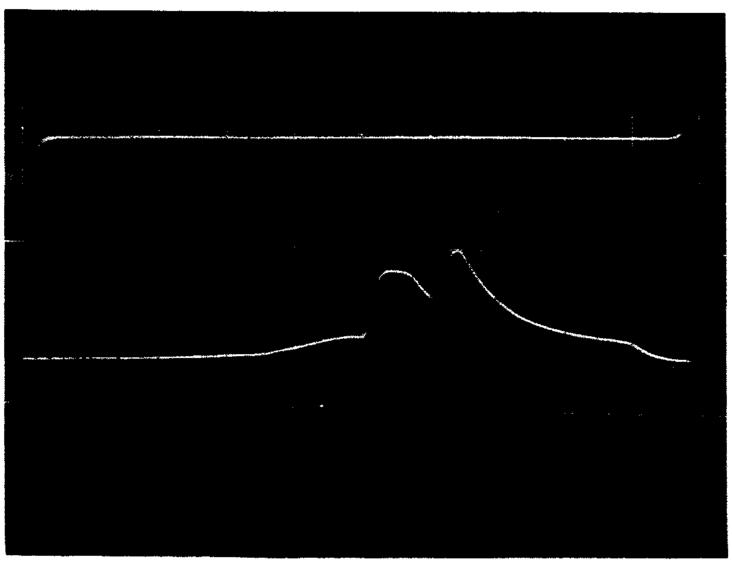


Fig. 8

1-4-64 11:30

Entry No. 5, Table I

H_2 Inlet Pressure = 300 psig

H_2 Inlet Temp. = 115°F

O_2 Inlet Pressure = 1125 psig

Vacuum = 164 mm Hg

Speed = 3070 rpm

Power = 2.39 HP

BSPC = 2.38 lb/hp-hr

BMEP = 116 psi

O/F = 1.61

% Heat Rejected = 72%

Oxygen timing was left unchanged and the hydrogen valve cutoff point was retarded to 40° ATDC (14% admission) for the runs of January 7. Results are given in Figs. 9 and 10 and in Entries 6 through 13 of Table I. The low BSPC of 1.9 lb/hp-hr achieved in this test and again on January 11 (Entry 4, Table II) represents the best performance to date with a 300 psig hydrogen inlet pressure. Thermal compression was good and indicated reasonably good ring sealing.

Hydrogen and oxygen timing were each retarded 10 degrees (giving the same overlap, which appears to be optimum) and the engine was tested with this timing on January 8. Results are given in Figs. 11, 12, and 13 and in Entries 14 through 22 of Table I. The appearance of the traces and the amount of thermal compression are similar. Retarding the timing of both valves another 10° gave 4% hydrogen admission and somewhat less thermal compression, as shown in Figs. 14 and 15 and Entries 23 through 28 of Table I Evidently the shape or size of the combustion chamber when ignition occurs near top center adversely effects combustion or propellant mixing.

An uncooled head with 8.5% clearance volume was used in the runs of January 11, shown in Entries 1 through 6 of Table II and in Figs. 16 and 17. Performance was very good for this power level, with low heat rejection. Thermal compression was low due to the low oxygen inlet pressure and low O/F ratios. Inlet hydrogen was not heated, due to a malfunctioning hydrogen heater. In this and subsequent runs the top 3 piece piston ring was replaced by an L-shaped compression ring designed for high unit pressures.

An attempt was made on January 14 to run the engine with low pressure hydrogen, admitted early in the cycle and compressed internally. Two oxygen valve settings were tried. These tests were unsuccessful since the engine did not develop enough power to overcome

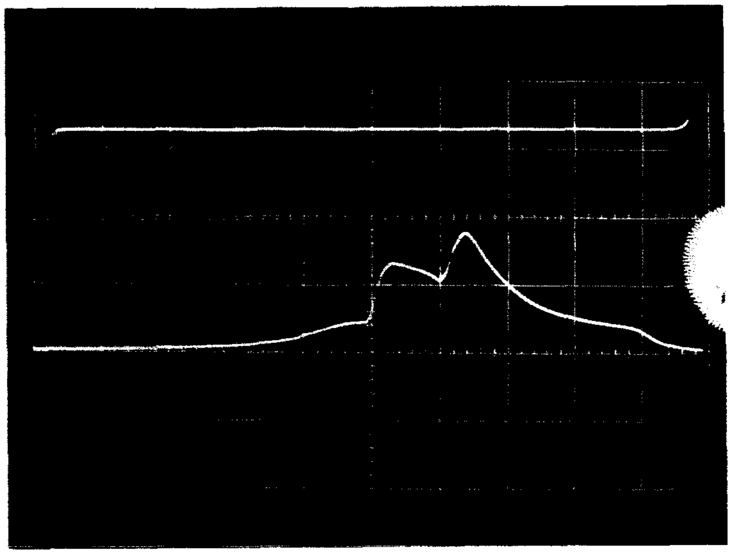


Fig. 9

1-7-64 4:25

Entry No. 12, Table I

H_2 Inlet Pressure = 300 psig

H_2 Inlet Temp. = 110°F

O_2 Inlet Pressure = 1100 psig

Vacuum = 178 mm Hg

Speed = 4010 rpm

Power = 3.96 HP

BSPC = 1.92 lb/hp-hr

BMEP = 144 psi

O/F = 1.32

% Heat Rejected = 48%

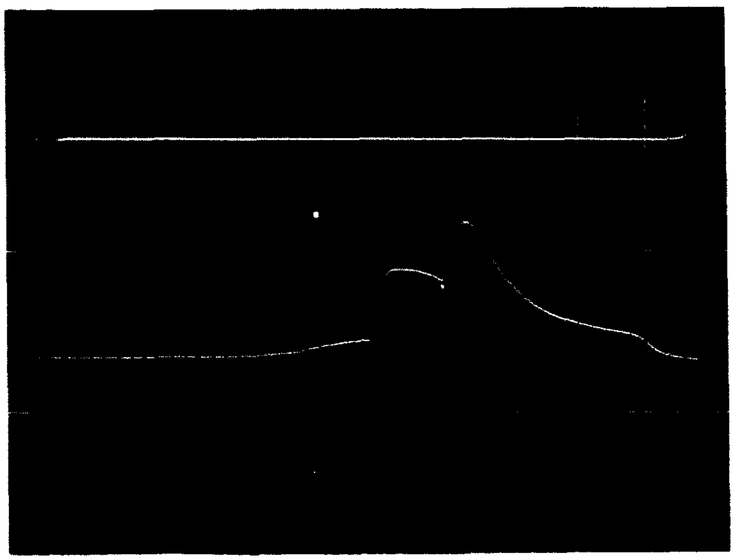


Fig. 10

1-7-64 4:30

Entry No. 13, Table I

H_2 Inlet Pressure = 300 psig

H_2 Inlet Temp. = 110°F

O_2 Inlet Pressure = 1100 psig

Vacuum = 110 mm Hg

Speed = 3020 rpm

Power = 3.47 HP

BSPC = 1.95 lb/hp-hr

BMEP = 167 psi

O/F = 1.57

% Heat Rejected 56%

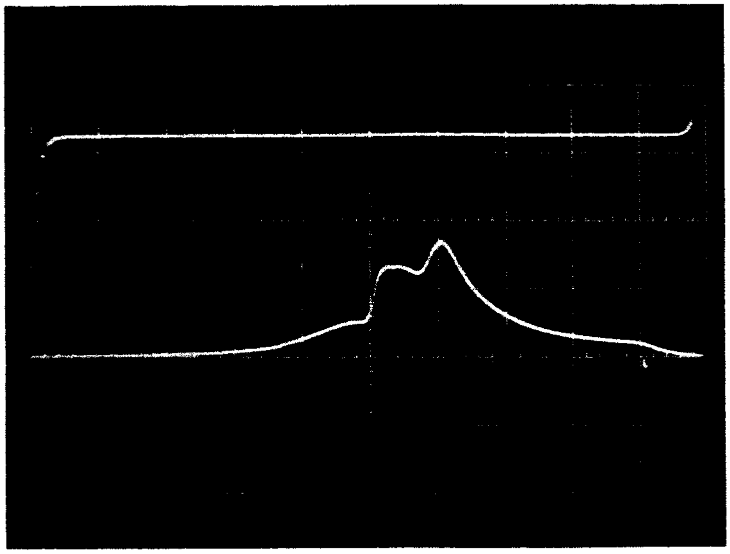


Fig. 11

1-8-64 3:58

Entry No. 19, Table I

H_2 Inlet Pressure = 300 psig

H_2 Inlet Temp. = 440°F

O_2 Inlet Pressure = 1000 psig

Vacuum = 241 mm Hg

Speed = 4040 rpm

Power = 2.67 HP

BSPC = 2.04 lb/hp-hr

BMEP = 96 psi

O/F = 1.56

% Heat Rejected = 64%

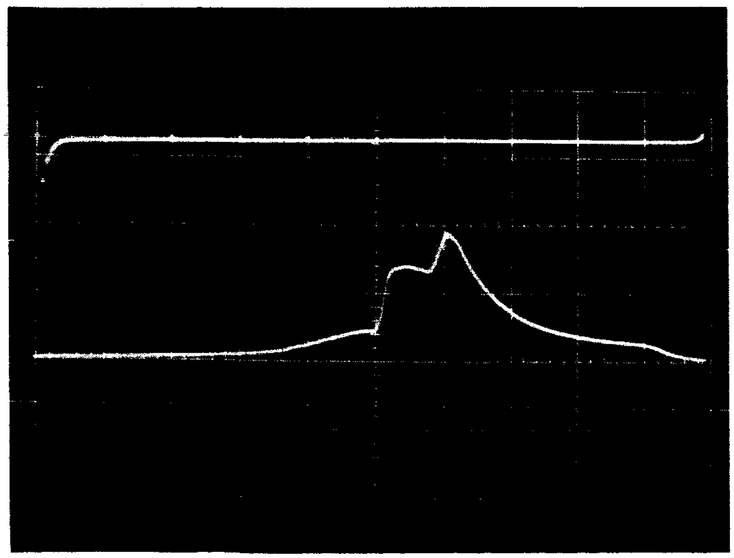


Fig. 12

1-8-64 4:01

Entry No. 20, Table I

H_2 Inlet Pressure = 300 psig

H_2 Inlet Temp. = 460°F

O_2 Inlet Pressure = 1000 psig

Vacuum = 210 mm Hg

Speed = 2990 rpm

Power = 2.15 HP

BSPC = 2.30 lb/hp-hr

BMEP = 105 psi

O/F = 1.95

% Heat Rejected = 79%

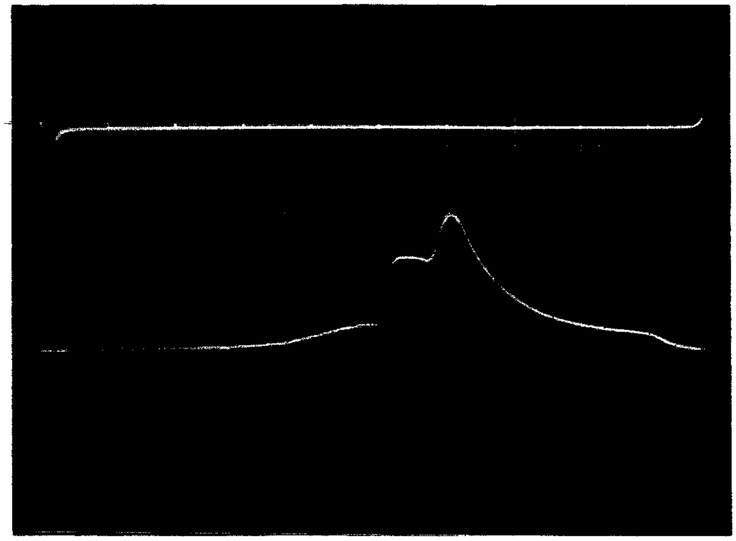


Fig. 13

1-8-64 4:13
Entry No. 22, Table I
H_2 Inlet Pressure = 300 psig
H_2 Inlet Temp. = 130°F
O_2 Inlet Pressure = 1000 psig
Vacuum = 150 mm Hg
Speed = 3000 rpm
BSPC = 2.16 lb/hp-hr
BMEP = 122 psi
O/F = 1.74
% Heat Rejected = 63%
Power = 2.52 HP

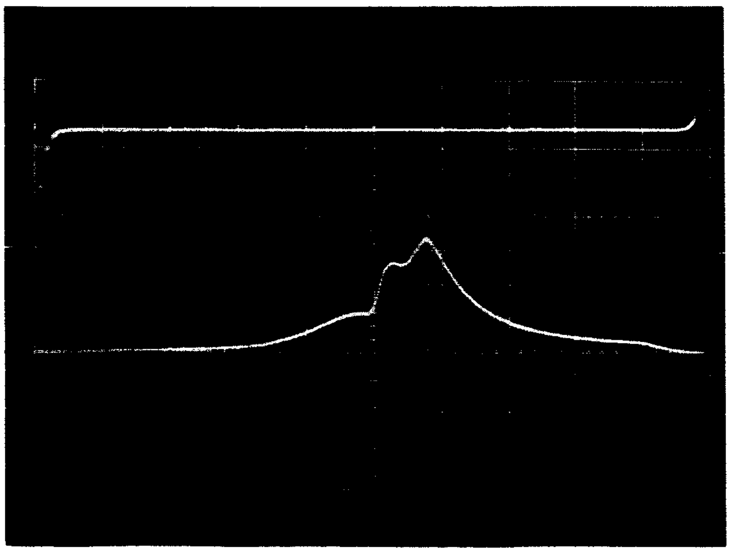


Fig. 14

1-9-64 2:53
Entry No. 25, Table I
H_2 Inlet Pressure = 300 psig
H_2 Inlet Temp. = 100°F
O_2 Inlet Pressure = 1000 psig
Vacuum = 290 mm Hg
Speed = 4040 rpm
BSPC = 2.16
BMEP = 85 psig
O/F = 1.66
% Heat Rejected = 73%
Power = 2.36 HP

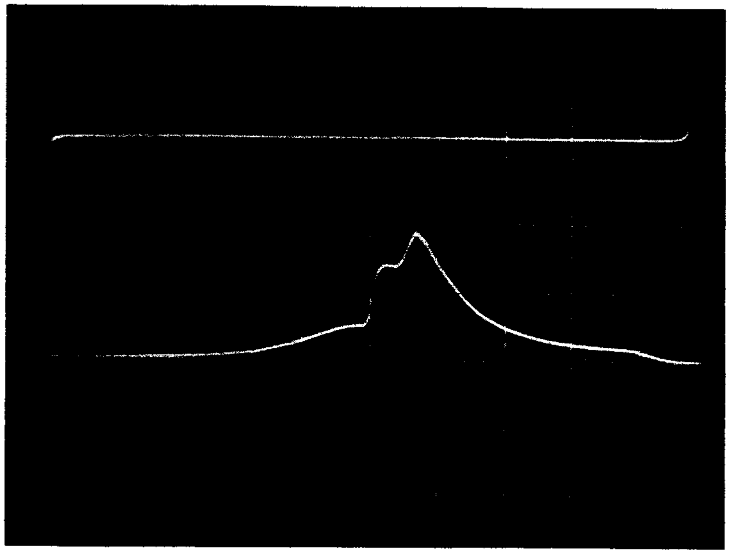


Fig. 15

1-9-64 2:57

Entry No. 26, Table I

H_2 Inlet Pressure = 300 psig

H_2 Inlet Temp. = 100°F

O_2 Inlet Pressure = 1000 psig

Vacuum = 250 mm Hg

Speed = 3010 rpm

BSPC = 2.49 lb/hp-hr

BMEP = 89 psi

O/F = 2.03

% Heat Rejected = 90%

Power = 1.84 HP

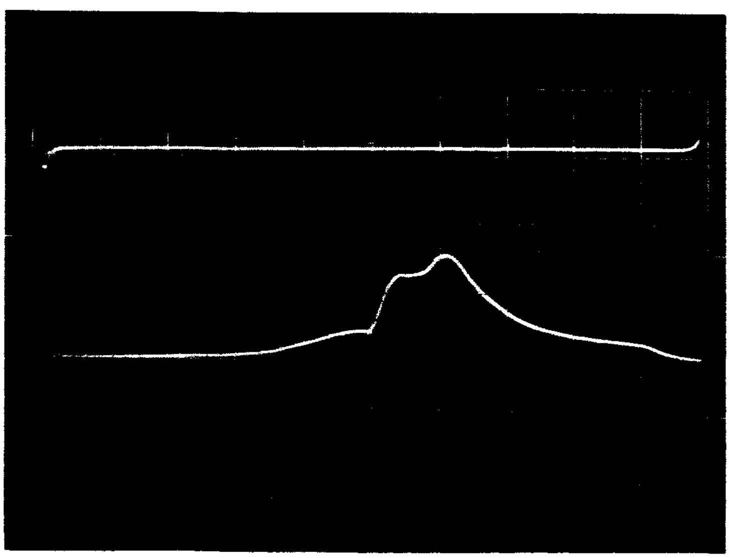


Fig. 16

1-11-64 3:05

Entry No. 5, Table II

H_2 Inlet Pressure = 300 psig

H_2 Inlet Temp. = 110°F

O_2 Inlet Pressure = 600 psig

Vacuum = 250 mm Hg

Speed = 4040 rpm

BSPC = 1.97 lb/hp-hr

BMEP = 108 psi

O/F = 1.16

% Heat Rejected = 54%

Power = 2.99 HP

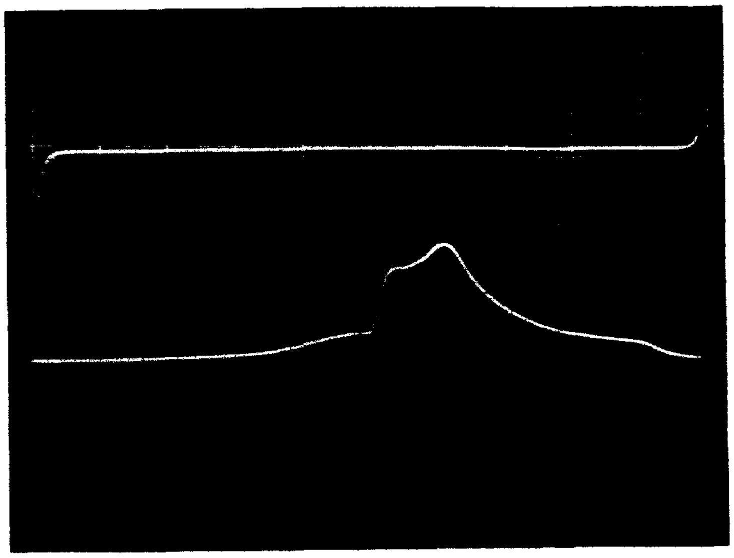


Fig. 17

1-11-64 3:12

Entry No. 6, Table II

H_2 Inlet Pressure = 300 psig

H_2 Inlet Temp. = 100°F

O_2 Inlet Pressure = 540 psig

Vacuum = 212 mm Hg

Speed = 3000 rpm

Power = 2.49 HP

BSPC = 1.96 lb/hp-hr

BMEP = 121 psi

O/F = 1.33

% Heat Rejected = 64%

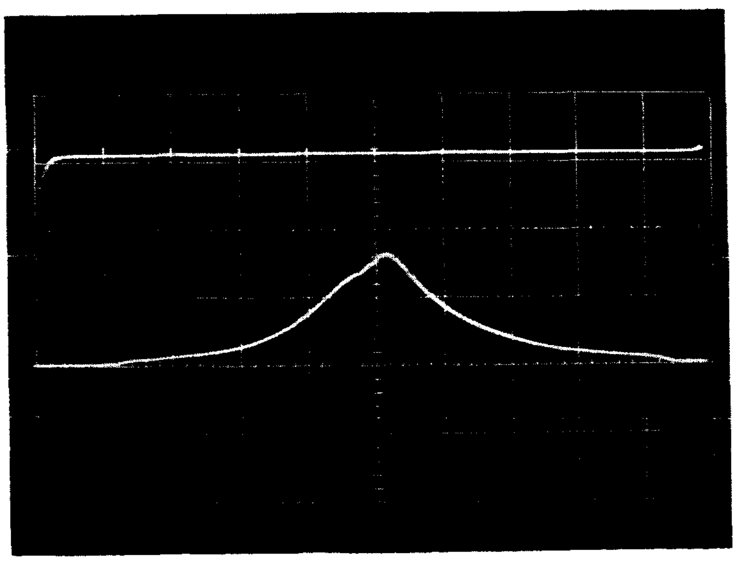


Fig. 18

1-13-64 2:10

Not Tabulated

Timing Condition No. 6

(Advanced H_2 Timing)

Approximately 2500 rpm at no load; i.e. the engine developed enough power to overcome internal friction at 2500 rpm. No vacuum.

internal friction at design speeds. The results are shown in Figs. 18 and 19.

Exhaust gas samples were taken on January 14. Ambient back pressure was required since the sampling techniques did not permit the use of a vacuum exhaust. Samples were taken by evacuated bottles at a point near the test cell wall, about 6 feet from the engine exhaust manifold. Exhaust temperature was nearly ambient. A spectrographic analysis of the samples was accomplished by NESCO (see Appendix C). The results are given in Table IV. Engine test data are given in Fig. 20 and in Entries 7 through 9 of Table II.

The oxygen and nitrogen correspond, within the limits of accuracy stated by NESCO, to about 1% air by volume. This is reasonable considering the sampling technique. The water vapor is approximately half of the amount generated by the engine according to the calculated O/F ratio. This is also reasonable since the exhaust was actively condensing at sample conditions, and appeared as a fog containing water droplets. Combustion, therefore, appears to be complete.

High power runs in the tests described earlier were at low O/F ratios due to the flow limitations of the oxygen injector using a 0.042" orifice. An orifice of 0.063" diameter was prepared and tests were run on 17 January using 14% hydrogen admission. The results are given in Entries 12 through 17 of Table II, and in Figs. 21, 22, and 23. This run terminated in a failure which is described in the Engine Assembly section. Probable leakage around the piston dome during the test may be responsible for the slightly poorer performance exhibited in this test when compared to the runs of January 7, which were performed under the same timing conditions but at a lower O/F ratio. Thermal compression in the latter tests was very high indicating rapid and complete combustion.

TABLE IV

MASS SPECTROMETER ANALYSIS OF EXHAUST GAS

Run	Engine Speed	Constituent	Volume %	Weight %
3:45	3000	O_2	.14	1.5
		N_2	.95	9.0
		H_2O	4.1	25.0
		H_2	94.8	64.5
3:50	4300	O_2	.17	1.7
		N_2	.93	8.3
		H_2O	5.3	30.4
		H_2	93.6	59.6
4:00	3000	O_2	.09	1.0
		N_2	.92	9.3
		H_2O	3.2	20.5
		H_2	96.8	69.2

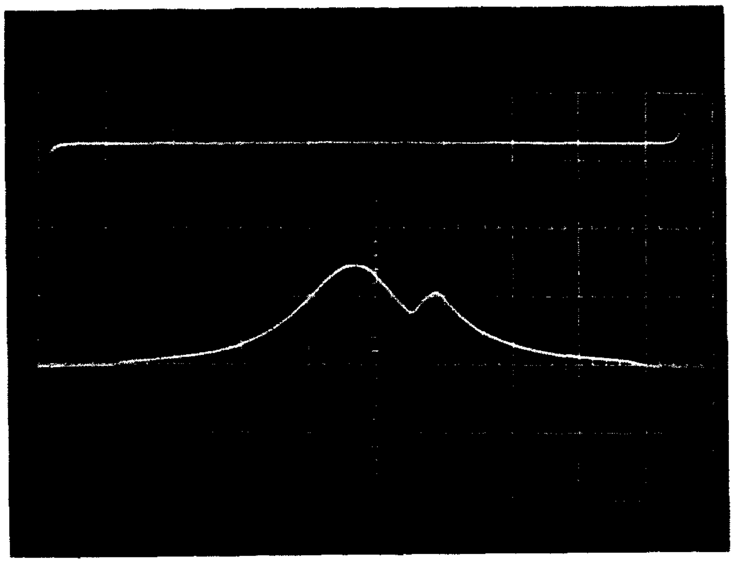


Fig. 19

1-14-64 11:10
Not Tabulated
Timing Condition No. 7
2200 rpm, approximately
1.0 in-lb output torque.
First peak is compression;
second peak is combustion.

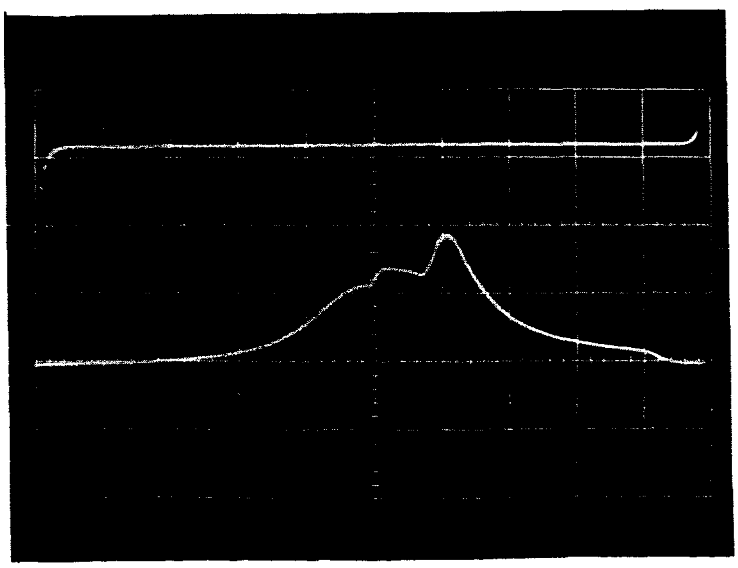
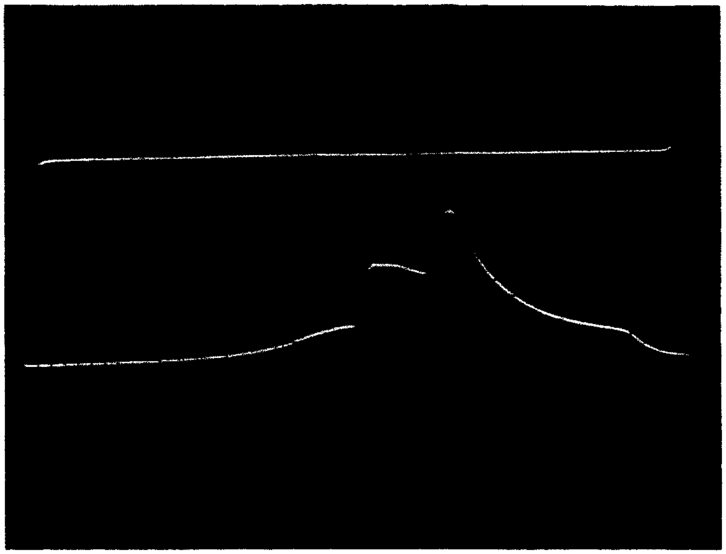


Fig. 20

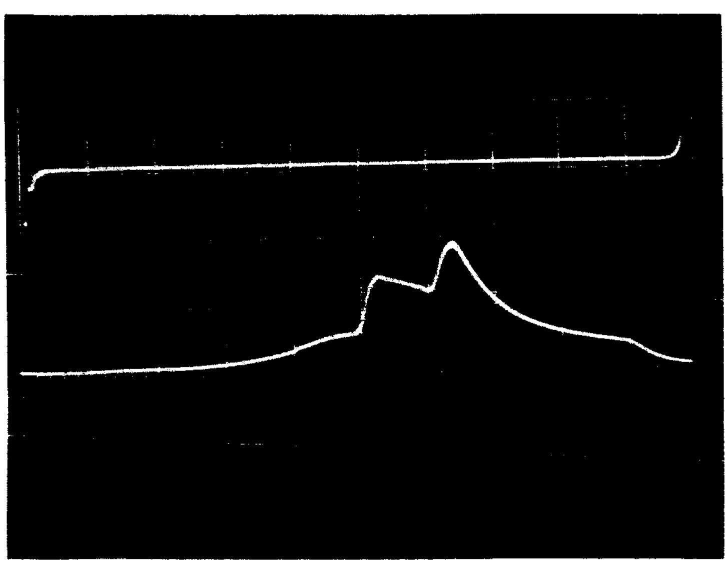
1-14-64 4:05
Entry No. 9, Table II
H_2 Inlet Pressure = 300 psig
H_2 Inlet Temp. = 85°F
O_2 Inlet Pressure = 900 psig
Vacuum = 760 mm Hg
Speed = 3000 rpm
Power = 1.83 HP
BSPC = 2.60 lb/hp-hr
BMEP = 189
O/F = 1.84
% Heat Rejected = 112

Fig. 21



1-17-64 3:46
Entry No. 13, Table II
H_2 Inlet Pressure = 300 psig
H_2 Inlet Temp. = 90°F
O_2 Inlet Pressure = 900 psig
Vacuum = 305 mm Hg
Speed = 3000 rpm
Power = 3.40 HP
BSPC = 2.16 lb/hp-hr
BMEP = 165 psi
O/F = 1.79
% Heat Rejected = 71%

Fig. 22



1-17-64 3:49
Entry No. 14, Table II
H_2 Inlet Pressure = 300 psig
H_2 Inlet Temp. = 95°F
O_2 Inlet Pressure = 900 psig
Vacuum = 305 mm Hg
Speed = 4010 rpm
Power = 4.01 HP
BSPC = 2.14 lb/hp-hr
BMEP = 146 psi
O/F = 1.64
% Heat Rejected = 58%

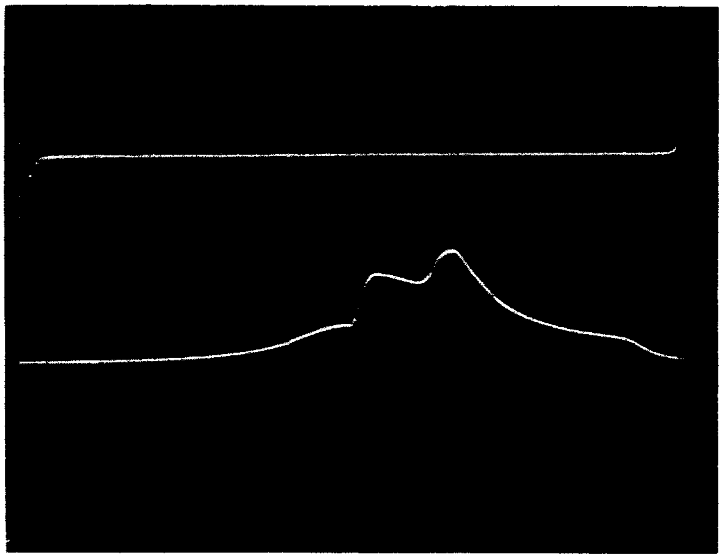


Fig. 23

1-17-64 4:12

Entry No. 17, Table II

H_2 Inlet Pressure = 300 psig

H_2 Inlet Temp. = 100°F

O_2 Inlet Pressure = 600 psig

Vacuum = 315 mm Hg

Speed = 4000 rpm

Power = 3.79 HP

BSPC = 2.03 lb/hp-hr

BMEP = 138 psi

O/F = 1.29

% Heat Rejected = 46%

Test Equipment

1. Fabrication of the new oxygen injector test block is completed.

2. Fabrication of the engine exhaust flow measuring system (described on Page 25 of PR 91570-510-6) is completed.

Compressor

Design and Fabrication

1. Based on experience obtained with the Rulon lined piston (Ref. PR 91570-510-6, Page 25 Para. 4) a new seal lip configuration was designed, Fig. 24.

   This piston assembly will be built from semi finished components, and will be finish machined to the new lip configuration.

   The difference between the previous and new lip design is that the latter has a stainless steel leaf spring type expander to give an additional lip flexibility.

Assembly

The No. 1 compressor was built up with the ringless Rulon A sleeved piston described in PR 91570-510-6 Progress Report, Page 25, Para. 4.

The No. 2 compressor was built up with Rulon A step gap piston rings.

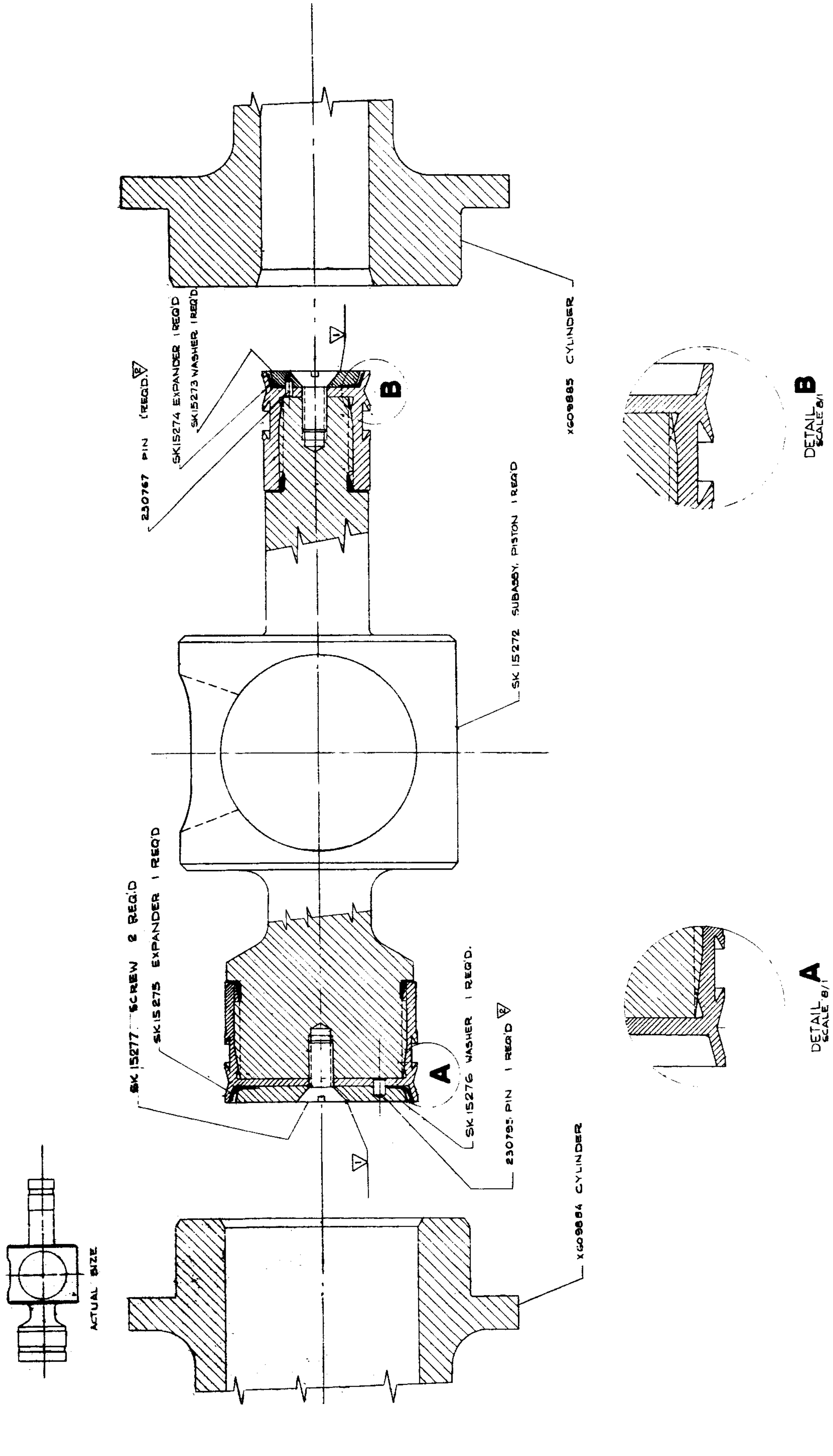


Fig. 24 - Piston Lip Seal Configuration

One first stage head has been built up with a large diameter inlet valve. (Ref. See above Progress Report, Page 25, Para. 3)

Performance Testing

1. The Rulon A sleeved piston was broken in for 1 hour and 42 minutes at various speeds. During this period the cylinder warm up time from 0°F to +60°F was monitored. This test was made in the past on Koppers and Rulon piston rings for comparison data. The Rulon A sleeved piston generated about the same amount of friction heat as the Rulon A step gap rings, which was the lowest between MACE, KOPPERS, and DIXON Rulon rings.

2. Next, flow and pressure data were taken at different speeds with the Rulon sleeved piston and the small diameter first stage inlet valve.

   Result: The large diameter inlet valve resulted in 20 percent higher flow under the same operating conditions than the small inlet valve assembly.

3. The above test was repeated on No. 2 compressor, using Rulon A piston rings. Flow and pressure was monitored with the small diameter first stage inlet valve and then with the large diameter first stage inlet valve. The data obtained on No. 2 compressor was compared with the corresponding data obtained on No. 1 compressor.

   Result: No. 1 compressor with Rulon A sleeved piston resulted in about 10-15% higher flow and about 30% higher pressure than No. 2 compressor with piston rings.

4. Conclusion - During the tests described above 5 hour 47 minutes were accumulated on the Rulon sleeved piston without showing any wear or damage on the lining. However, it was noted that the sealing lip of the piston may take a permanent set due to overheating, or the lip may leave the cylinder wall due to excessive cool down. The above problem was anticipated since the very small stiff lip was designed without expander to eliminate a complex design. Feasibility of this piston design was proven during the tests, so an improved design was released as outlined in the Design & Fabrication section.

The breathing of the compressor, and therefore, its efficiency, is better with a large diameter first stage inlet valve. During the test runs with both valve sizes it became evident that the valves are floating at above 2000-2500 rpm. Since this depends mainly on the valve springs, guide friction, valve mass, operating speed and piston leakage, more development work is needed to correlate all these factors to get to the most efficient operation.

Test Equipment

The development of the test equipment goes parallel with the compressor development. To date, data obtained has been mostly of comparative value. Unsophisticated instrumentation has been satisfactory since the compressor was not mechanically in perfect running condition. As compressor performance is improved, instrumentation and test facility shortcomings become apparent and are corrected. Following corrective steps were taken:

1. Hydraulic drive unit was moved out of the control room. This will improve test conditions by reducing the noise level, further improvements were made in speed control.

2. Electronic instruments were mounted in an instrument cabinet to make the readout more convenient.

3. The Wheelco temperature recorder is being recalibrated for copper-constantain thermocouples which are more suitable for cryogenic application. The range of the instrument will be also changed to handle all temperatures from -350° to +300°F.

4. A new torque pickup will be obtained with a lower range. The range of the present torque pickup is 100 inch-lb which is too high, therefore, the readout is inaccurate. The range of the new torque pickup will be based on actual test results.

Regenerator

Design of new test equipment for operating the regenerator under vacuum conditions is in process.

PROTOTYPE ENGINE ENDURANCE TEST

Design and fabrication of the endurance test facility is in process.

RELIABILITY AND QUALITY ASSURANCE

During January the only milestone scheduled (See Fig. 25) was the preparation of H_2-O_2 Engine Test Procedures which has been completed on schedule. These are submitted in Appendix A.

Two meetings were held during the month between the NASA Western Operations Office Reliability and Quality Monitor, and the Vickers Incorporated Reliability personnel. Areas that were closely monitored during these two visits were:

> Vickers progress in correcting instrumentation control deficiencies and Vickers failure reporting system.

A description of the accomplishments relating to each reliability program milestone is given below.

Reliability and Quality Assurance Function for Task I (Flight-Type Power System Design)

Design Review

No work was scheduled during this reporting period.

Reliability and Quality Assurance Function For Task II (Prototype Component Development)

Drawing Control Procedures

Drawing control procedures were prepared in December and presented in that month's report.

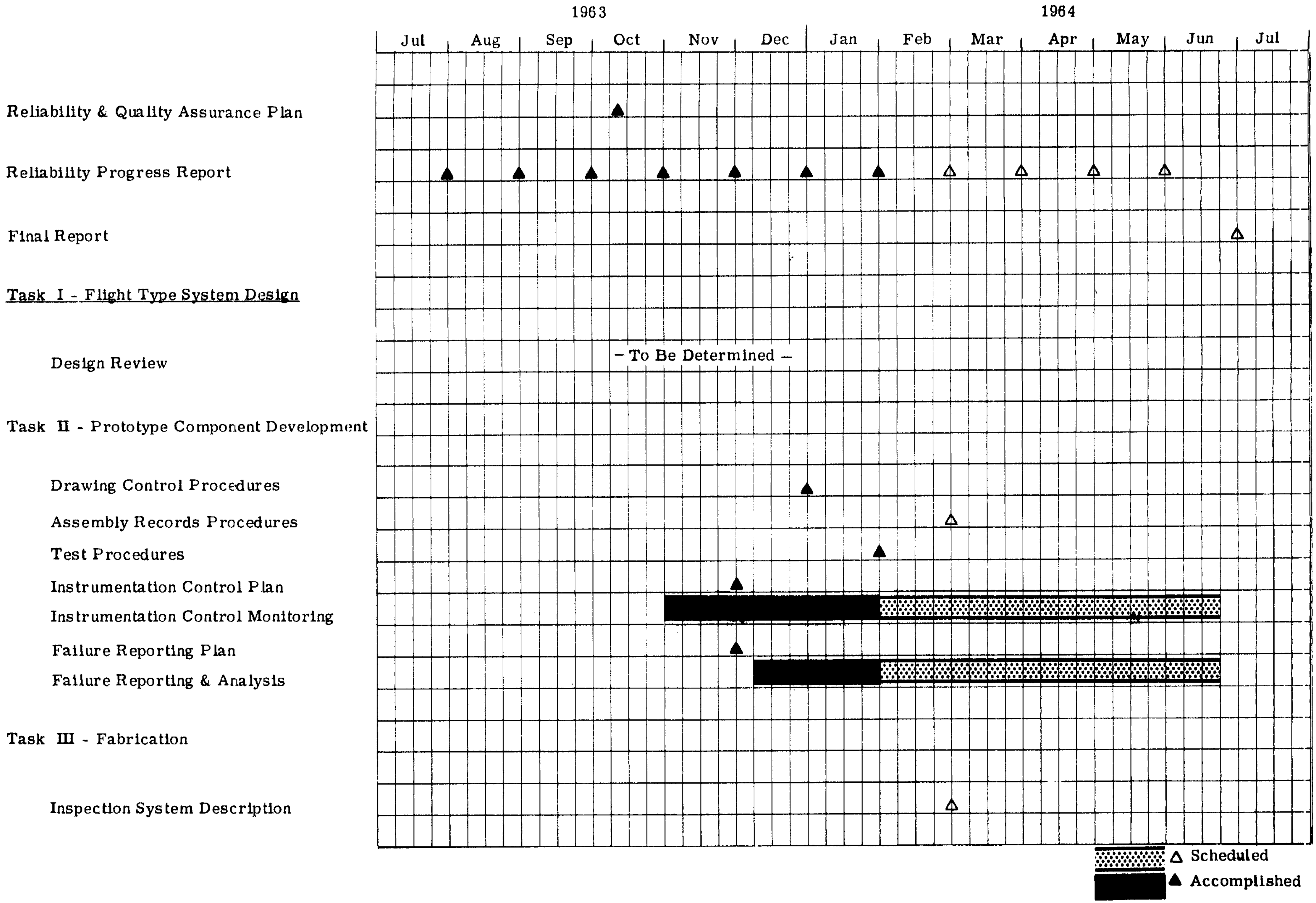


Fig 25 - Reliability and Quality Assurance Program Plan Milestone Chart

Assembly Build-Up and Parts Records

A written description of the assembly and parts record procedures, now in use for the engine and compressor, will be prepared during the month of February and presented in the February Progress Report. These records have been made available to NASA personnel and appear to be adequate.

Test Procedures

Formal test procedures for the H_2-O_2 engine were completed during the month of January and are presented in Appendix A. These procedures will serve to minimize possible variations in conducting tests that might exist among individual test operators.

Instrumentation Control

An inspection was undertaken by the NASA reliability monitor of the H_2-O_2 engine test equipment and gages. Although some instrumentation needed recalibration, considerable improvement was noted over the previous reporting period. For example, most of the out-of-control instrumentation was calibrated. The only devices that remain "past due" are those which cannot be calibrated in-place and for which there are presently no replacements. Arrangements should be complete in February for the systematic and periodic calibration of all instrumentation. Also, all gauges are now fixed with item numbers to simplify identification of the specific performance parameters and eliminate the possibility of a placement error when recording values. A written procedure to document this system is also being prepared and will be completed during February.

Failure Reporting and Analysis

Monitoring of all failures of the H_2-O_2 engine continued as previously described. During the month, one new failure mode was recognized and coded as follows:

> A piston dome retaining screw failure (2D). This failure was attributed to high installation torque (approaching yield strength) in combination with high temperature due to gas leakage past the piston dome seal. A description of engine damage resulting from this failure is given in the Engine Assembly Section.

Reliability and Quality Assurance Function for Task III (Fabrication)

There was no additional work accomplished by Reliability and Quality Assurance for Task III. A brief description of Vickers inspection and material review board procedures was made in the November report.

APPENDIX A

ENGINE TEST PROCEDURES

PROCEDURES FOR ADJUSTING ENGINE TIMING

OXYGEN VALVE TIMING

A. The following instructions apply to changing the oxygen valve timing while the engine is on the test stand.

1. Remove the flywheel and the front timing gear cover. Be careful not to damage the mating surfaces of the cover. Also remove the oil supply lines to the oxygen valve cover.

2. Disconnect the oxygen line and remove the fitting from the injector.

3. Remove Allen screw from left side of the oxygen body.

4. Install the dial indicator mounting bracket on the screw hole of the oxygen valve body with the Allen screw supplied with the dial indicator, and be sure that the dial indicator shaft rests squarely on the end of the poppet valve stem.

5. Back off the lock nut on the adjusting screw.

6. Turn adjusting screw so that there is 0 clearance on the heel of the cam by observing the dial indicator. It may be necessary to turn the lock screw slightly further than the very first small movement observed to obtain true 0. The point at which the dial indicator starts to move rapidly off of the dial indicator 0 point is true 0. This can be as much as .0002-.0003 above the first observed dial indicator 0. (Repeat several times to insure consistent readings).

7. Rotate the engine by hand in direction of engine rotation until maximum lift is observed on the dial indicator. (Repeat several times to insure consistent readings).

8. With the reading on the highest point, back off the adjusting screw approximately .002 for valve clearance and retighten the adjusting lock nut. Rotate a few times to check for proper lift. (Should be .002 less than maximum lift).

9. Remove the screw holding the oxygen cam to gear while dial indicator is at highest point (Mid Point).

10. Rotate the engine backward to advance timing and forward to retard timing. The cam should stay stationary at midpoint during this operation for correct timing. If the cam did move, hold the crankshaft in proper position and pry the cam around to the correct position.

11. Replace the oxygen cam lockscrew and tighten securely.

12. Rotate the engine several times to double check mid point reading against the degree wheel.

13. Remove the dial indicator and replace L. H. oxygen body screw. Install the oxygen supply line and fittings. Install steel spring seat on follower spring adjusting screw. Install oxygen valve follower spring and cover assembly. Replace all oil lines and fittings. Remove degree wheel from the flywheel.

HYDROGEN VALVE OPENING TIMING

A. The following instructions apply to setting the hydrogen valve opening timing while the engine is on the test stand.

1. Remove the oil supply lines and the hydrogen valve cam cover.

2. Remove hydrogen valve cam mechanism oiler.

3. Install protractor on the flywheel.

4. To set opening of the valve from 10 degrees before top center to 5 degrees before top center for example, put 50 psi nitrogen pressure on the valve assembly.

5. Turn crankshaft in normal direction of rotation until hiss is heard at 10 degrees before top center.

6. Remove the outside diameter screw from the cam.

7. Turn crankshaft to read 5 degrees BTC against normal engine rotation (backwards). If cam did not move with the shaft, approximate timing has been achieved. Note: If the cam did turn with the shaft, return crankshaft to original setting at 10 degrees BTC, then loosen the inside screw and this will release the cam. Rotate the crankshaft back to 5 degrees BTC, now insert a small punch in adjusting screw holes and carefully pry cam around until hiss is heard at 5 degrees BTC. Approximate timing has been achieved.

8. Install the outside diameter screw and tighten. Also tighten the inside screw, then rotate the engine a few times in normal direction and check hissing sound at 5 degrees BTC. If timing is off one or two degrees, it is possible to just loosen the outside screw and obtain correct timing by moving cam within the tolerance of the screw hole. Retighten the screw and check to see that the valve closing timing has not been affected by loosening of the inside screw. If timing has been affected, loosen the inside screw and adjust cam within tolerance of the screw hole to correct valve closing timing.

9. Re-install the cam oiler and the cam cover. Install all oil lines and the fittings.

10. Release 50 psi nitrogen pressure on the valve system.

CHANGING HYDROGEN VALVE CLOSING TIMING

A. The following instructions may be used as a guide in changing the hydrogen valve closing timing while the engine is on the test stand.

   1. Remove oil lines and the hydrogen valve cam cover.

   2. Remove the hydrogen valve cam mechanism oiler.

   3. Install the degree wheel on the flywheel and apply 50 psi N_2 pressure on the valve system.

   4. To set the hydrogen valve closing timing for example from 20 degrees A. T. C. to 25 degrees A. T. C.

5. Turn the engine against normal rotation until hissing sound is heard at 20 degrees A. T. C.

6. Remove the inside diameter lock screw on the cam and loosen the outside screw on the cam.

7. Rotate the engine in normal direction to 25 degrees A. T. C. then pry the cam around until hissing sound is heard.

8. Replace the inside cam lock screw and tighten it, then tighten the outside screw.

9. Rotate the engine a few times and then check for correct valve closing timing at 25 degrees A. T. C. by turning the engine against rotation until hissing sound is heard. If it is one or two degrees off, loosen inside cam lock screw and move cam to correct timing within tolerance of the screw hole.

10. Tighten the screws and re-check the timing with nitrogen pressure again.

11. Replace the hydrogen valve cam mechanism oiler and the valve cam cover. Replace the oil lines and fittings.

12. Release the 50 pounds N_2 pressure on the valve system.

PROCEDURE PRIOR TO H_2-O_2 ENGINE TEST RUN

1. Turn on all instrumentation power at least one hour before test run.

2. Adjust nitrogen pressure regulator to 1500 psi. Regulator is located on south wall of test cell.

3. Pressurize Dowthern cooling system reservoir by adjusting N_2 pressure regulator located on reservoir on exterior north wall of test cell to 25-30 psi. Start Dowthern pump by pushing start button located to left of control console (not shown in diagram).

4. Bring Dowthern cooling system to 180°F by allowing it to run without cooling water flow to the heat exchanger.

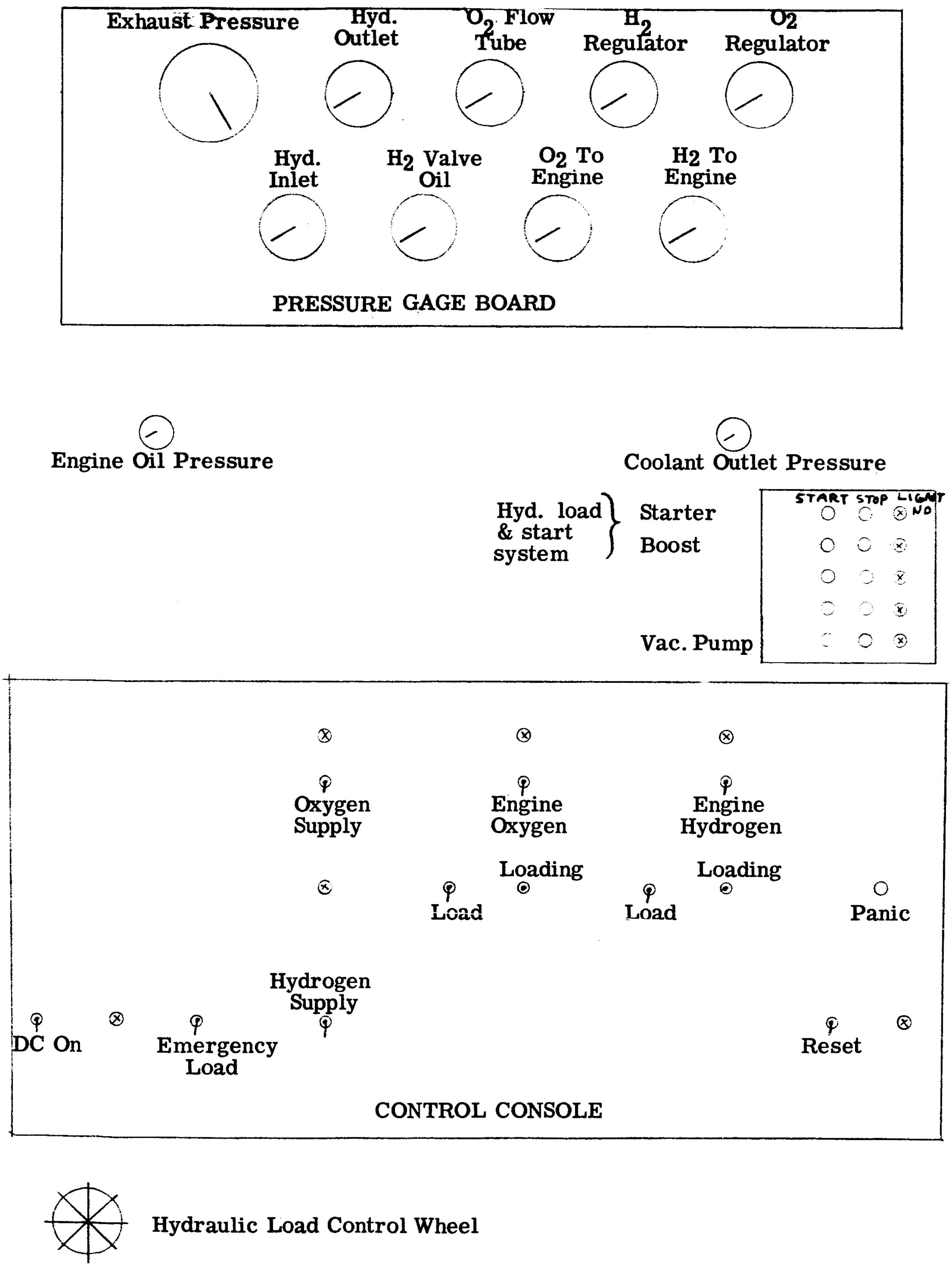
5. Turn on main engine oil pump (switch located underneath oil reservoir in test cell). Run pump until oil temperature reaches 125°F.

6. After coolant and oil are at the above temperatures, turn off pumps and calibrate load cell with known weights. This may require adjusting the torque read-out instrument.

7. Turn on coolant and oil pumps again.

OPERATING PROCEDURE - H_2-O_2 ENGINE

1. Apply 500 psi pressure to the O_2 injector by pushing the load switch up while observing the O_2 to engine pressure gauge in the cell.


Exhaust Pressure
Hyd. Outlet
O_2 Flow Tube
H_2 Regulator
O_2 Regulator
Hyd. Inlet
H_2 Valve Oil
O_2 To Engine
H_2 To Engine
PRESSURE GAGE BOARD
Engine Oil Pressure
Coolant Outlet Pressure
Hyd. load & start system
Starter
Boost
Vac. Pump
START
STOP
LIGHT NO
Oxygen Supply
Engine Oxygen
Engine Hydrogen
Loading
Loading
Load
Load
Panic
Hydrogen Supply
DC On
Emergency Load
Reset
CONTROL CONSOLE
Hydraulic Load Control Wheel

2. Push the H_2 load switch up.

3. Turn hydraulic load control wheel counter clockwise until it stops.

4. Turn on water valve (located in test cell on west wall) for the Kistler transducer cooling.

5. Turn on H_2 valve oil pump (switch located under oil reservoir in test cell).

6. Turn on H_2 valve oil line valve located on test stand.

7. Turn on oil mist for test stand bearings by opening the valve on west wall of test cell.

8. Turn on O_2 pressure at tanks by opening valve on tanks.

9. Turn on H_2 pressure at tanks by opening valves on tanks.

10. Be sure there is adequate operating pressure in the supply tanks for the planned test duration.

11. Rotate engine backwards until resistance is encountered.

12. Push starter and boost buttons simultaneously and push H_2 loading switch up to obtain 300 psi while observing the H_2 pressure gauge in the cell. Hydraulic system should be set for a no-load engine motoring speed of 2000 rpm.

13. Check engine for leaks while motoring under hydraulic power, using "SNOOP."

14. If leaks are detected, determine their extent and location. Push "Off" starter and boost buttons simultaneously.

15. Push H_2 load switch down to release all pressure.

16. For minor leak repairs, such as replacing catalyst plug gaskets, all other settings may be left as is. If a major leak repair is required, reverse previous operations in order.

17. If a minor leak was repaired, continue operations starting with Step 10.

18. If no leaks were detected, turn hydraulic load wheel clockwise to obtain 400 psi pressure on the hydraulic outlet gauge in the cell.

19. Check all gauges to be sure pressures are still as they were set.

20. Push reset switch up and release when light comes on.

21. Push hydrogen supply switch up and then push the engine hydrogen switch up.

22. Be sure H_2 is flowing through the engine before continuing further. Flow through the engine may be confirmed by observing a scope trace and/or hearing the sound of the engine change.

23. Turn on Wheelco strip chart temperature recorder.

24. Push oxygen supply switch up and then push the engine oxygen switch up.

25. The engine should start in about 15 or 20 seconds.

26. Oxygen or hydrogen pressure may have to be raised or lowered to get engine to start. (Note: do not lower O_2 pressure below 400 psi).

27. If the engine is running and a condition arises that requires the combustion to be stopped immediately, pushing the panic button will allow nitrogen to plunge out the O_2 and H_2 in the engine.

28. When engine starts, adjust engine speed to 3000 rpm.

29. Switch on torque readout.

30. Allow engine to warm up for two or three minutes before changing pressures. Observe cylinder head temperature to determine characteristics of the engine set up.

31. Set gas pressures and rpm specified for the engine test. Monitor cylinder head temperature at all times.

32. If heated H_2 is required, switch on H_2 heater, set temperature required and set kv control for desired rate of heating.

33. Using heated H_2 will cause the cylinder head temperature to rise slightly.

34. To turn off H_2 heater, turn kv control off and heater switch off.

35. If the vacuum system is to be used, first set engine speed to 3000 rpm. Push vacuum pump "On" button and close pump bypass valve. Vacuum may be adjusted by opening or closing the gate valve. Both valves are located on vacuum pump.

36. Readjust engine speed to the required rpm by turning hydraulic load control wheel.

37. To shut off vacuum system, push "Off" button and open pump bypass valve.

38. To shut off engine at end of test, lower O_2 pressure to cool off cylinder head temperature.

39. After temperature has cooled to approximately 800° - 900° push engine oxygen switch down and then push oxygen supply switch down.

40. When combustion ceases, push engine hydrogen switch down and then push hydrogen supply switch down.

41. Push panic button to insure that O_2 and H_2 cannot flow to the engine anymore.

42. Turn on or increase cooling water to Dowthern heat exchanger to cool down Dowthern system and engine.

43. Let engine motor for a few minutes to ensure that all H_2 has been expelled from engine and to allow more cooling off.

44. Push starter and boost buttons off simultaneously.

45. Push H_2 load switch down.

46. When engine stops rotating, turn off both oil pumps, oil mist valve and H_2 oil line valve.

47. Push O_2 load switch down.

48. After engine is cool, turn off Dowthern system and Kistler transducer water.

APPENDIX B

FAILURE REPORT AND SUMMARY SHEETS

ENGINE FAILURE MODES

1. Oxygen Injector

    A. Broken flex pivot
    B. Static seal leak
    C. Bushing to shaft seizure
    D. Leak spring retainer deformed
    E. Flame plated valve worn

2. Engine

    A. H_2 valve assembly leakage
    B. Catalyst plug gasket leak
    C. H_2 valve retainer ring broke
    D. Piston dome retaining screw broke

SHEET NO. 1 of 3

VICKERS INCORPORATED
FAILURE REPORT & SUMMARY SHEET
FOR NASA CONTRACT NASA 3-2787
MARK I H_2 - O_2 ENGINE MODEL EA-1570-515

Note: 1. Initial and Date Items you fill in, 2. Rework SF No.'s. can be used as Serial No.'s.

Failure No.	Data Sheet No. Time & Date of Failure	Part Name	Part No. & Serial No.	Description of Failure (The Part Condition)	Description of Conditions (Active on Part prior to Failure)	Failure Mode No.	Cumulative Time on Part in Minutes	Action Taken
1	D.S. 18	O_2 Injector Flex Pivot	X610104	Broken Flex Pivot	Engine shut down due to tendency of oxygen valve to stick open.	1A	70 Cold 41 Hot	New flex pivot installed
2	D.S. 21	O_2 Injector Flex Pivot	X610104	Broken flex pivot	Engine cylinder head temperature was low and could not be increased.	1A	257 Cold 75 Hot	New flex pivot installed; poppet refinished and lapped; seat guide lapped.
3	D.S. 23	O_2 Injector Face Seal	X610113	Leaking haskel seal	Engine stopped because O_2 ΔP gauge showed increasing flow.	1B		New seal installed.
4	D.S. 23	O_2 Injector Flex Pivot	X610104	Flex pivot broken	Cylinder head temperature could not be raised to 1400°F and O_2 flow fluctuated excessively.	1A	88 Hot	Pivot removed and replaced with a new stainless flex pivot.
5	D.S. 27, 28 - 10-12-63	O_2 Injector Flex pivot	X610104	All three bands of O_2 injector flex pivot broken.	Engine stopped when O_2 flow fluctuated excessively.	1A	142 Hot	New flex pivot installed.
6	10-18-63	O_2 Injector Bushing	X611376	Flame plated bearing seized in bushing. Bushing had started to come out of body.	Engine started and O_2 flow increased to full flow.	1C	68 Cold 1 Hot	Bushing pressed back into body.
7	D.S. 33	O_2 Injector Bushing	X611376	O_2 Injector was sticking. Flame plated bushing and shaft seized together.	Engine stopped when O_2 flow became erratic.	1C	37 Hot	Bushing honed out for an .0008 to .001 clearance and counter-bored to prevent end of shaft from rubbing on bushing.

VICKERS INCORPORATED
FAILURE REPORT & SUMMARY SHEET
FOR NASA CONTRACT NASA 3-2787
MARK I H_2 - O_2 ENGINE MODEL EA-1570-515

SHEET NO. 2 of 3

Note: 1. Initial and Date Items you fill in, 2. Rework SF. No.'s. can be used as Serial No.'s.

Failure No.	Data Sheet No. Time & Date of Failure	Part Name	Part No. & Serial No.	Description of Failure (The Part Condition)	Description of Conditions (Active on Part prior to Failure)	Failure Mode No.	Cumulative Time on Part in Minutes	Action Taken
8	11-1-63	O_2 Injector Retainer	X611378	The leaf spring had been deformed around end of valve.	Normal inspection of O_2 injector.	1D	247 Hot	New retainer installed.
9	11-13-63	O_2 Valve	X611402	Some flame plated material came off seat area.	Test stand used for test valve run using cold gas.	1E	68 Cold	Valve sent to NASA Lewis for examination.
10	11-16-63	O_2 Injector Retainer	X611378	The leaf spring had been deformed around end of valve.	Normal inspection of O_2 injector.	1D	232 Hot	New retainer installed.
11	11-19-63	H_2 Valve Assembly	X611414	Seals in H_2 valve assembly leaking.	Engine stopped when flames were observed coming from H_2 valve assembly.	2A	230 Hot	New H_2 valve assembly seals installed. One copper seal made. H_2 manifold brazed.
12	12-7-63	O_2 Injector Valve	X611402	Some flame plated material came off seat area.	Test stand used for test valve run using cold gas.	1E	30 Cold	Valve to be returned to Linde Co. for examination and recommendation.
13	11-21-63	H_2 Valve Assembly	X611414	Seals in H_2 valve assembly leaking.	Engine stopped when flames came out of H_2 valve assembly.	2A	6 Hot	New seals installed.
14	11-23-63	O_2 Injector Valve	X611402	Excessive wear on guide area of valve (flame plated).	Engine stopped when O_2 injector could not be controlled.	1E	300 Hot	Valve sent to NASA Lewis for metallurgist examination.

VICKERS INCORPORATED
FAILURE REPORT & SUMMARY SHEET
FOR NASA CONTRACT NASA 3-2787
MARK I H_2 - O_2 ENGINE MODEL EA-1570-515

Note: 1. Initial and Date Items you fill in, 2. Rework SE No.'s. can be used as Serial No.'s.

Failure No.	Data Sheet No. Time & Date of Failure	Part Name	Part No. & Serial No.	Description of Failure (The Part Condition)	Description of Conditions (Active on Part prior to Failure)	Failure Mode No.	Cumulative Time on Part in Minutes	Action Taken
15	12-12-63	O_2 Injector Retainer	X611378	The leaf spring retainer had been deformed around the end of the valve.	Normal inspection of injector.	1D	552 Hot	New retainer installed.
16	12-12-63	H_2 Valve Assembly Ring	X610171	The H_2 valve ring had worn through.	Normal disassembly for inspection of O_2 injector.	2C	819	New ring installed.
17	12-20-63	H_2 Valve Assembly		H_2 valve assembly leakage.	Engine stopped when fire came out of the top seal of the H_2 valve assembly. Note: The three screws had loosened and may have caused the leak.	2A	41 Hot	New seals installed.
18	1-17-64	Piston Dome Retaining Screw	X611408	The piston dome retaining screw failed in tension allowing the piston dome to jam between the piston and cylinder head, thus causing the engine to stop abruptly.	Engine had been run hot for 43 minutes when a strange noise started followed by an abrupt stop of the engine.	2D	540 Cold 376 Hot	Use new piston design now being fabricated. Interum Corrective Action: 1. Reduce installing torque from 80in-lb. to 50 in-lb. 2. Design rework to reduce or eliminate leakage and to increase screw diameter.

APPENDIX C

ENGINE EXHAUST ANALYSIS

Aerospace and Geomarine Technology

NATIONAL ENGINEERING SCIENCE COMPANY

711 SOUTH FAIR OAKS AVENUE • PASADENA, CALIFORNIA • SYcamore 5-8461

HOUSTON, TEXAS • NEWPORT BEACH, CALIFORNIA • WASHINGTON, D. C.

January 21, 1964

Mr. W. Morath
Vickers Incorporated
3201 Lomita Boulevard
Torrance, California

Dear Mr. Morath:

Following are results of analyses on three samples submitted to us on your P.O. T-63532. The price is $75.00 total.

Sample #	3000-4:00	3000-3:45	4300-3:50
O_2	0.092	0.14	0.17
N_2	0.92	0.95	0.93
H_2O	3.2	4.1	5.3
H_2	remainder	remainder	remainder

The figures are volume percentages and we point out that the small oxygen percentages are estimated accurate to $\pm$ 0.05. With such small peaks as these oxygen percentages represent, background noise interferes at high attenuations necessary to pick them up. We also call attention to the fact that air may not have been entirely removed from the space before the stopcock. If this is so, then the oxygen values are higher than they should be. If your sample sequence is such that 3000-4:00 was the last sample taken, then it may be inferred that air was not entirely removed from the space in front of the stopcock - this latter sample shows the smallest percentage of oxygen and presumably was the last sample taken. The variation in water analyses may be related to sampling methods but may also be related to water absorption in the mass spectrometer. This instrumental surface absorption of water leads to continued outgasing and progressively higher water analyses with like samples.

We will keep the samples in case further data are desired by you.

Very truly yours,

National Engineering Science Co.

H. Landesman, Ph.D.
Senior Staff

HL/hg
cc: Mr. Ron Thomas, Vickers Inc.

APPENDIX D

TEST PLAN FOR FEBRUARY, 1964

TEST PLAN FOR FEBRUARY, 1964

1.0 Endurance Tests

1.1 Number of Tests: 2-4

1.2 Description: The engine will be run at moderate speeds and and high power levels for 8 or 12 hours. Data will be recorded at half hour intervals. Critical dimensions will be recorded before and after to determine wear rates. Two 8 hour and one 12 hour endurance test are planned for February.

1.3 Operating Parameters: 3000 rpm, 300 psig hydrogen pressure, 500°F hydrogen temperature, 150 mm hg exhaust pressure, timed to give a torque of 150 - 200 psi BMEP. O/F = $1.0/_1$ to $1.2/_1$.

1.4 Estimated Running Time: 30 hours includes break-in and shakedown time.

2.0 Heated Inlet Tests

2.1 Number of Tests: 2-4

2.2 Description: Hydrogen inlet temperature will be varied in steps to the highest allowable value. Other parameters will be held constant.

2.3 Operating Parameters: Timing will be adjusted to yeild 2.5 to 3.5 hp. 300 psig H_2 inlet pressure, 3000 and 4000 rpm, and mixture ratio will range between $1.0/_1$ and $2.0/_1$ °F.

2.4 Total Running Time: 3 hours

3.0 Head Cooling Tests

3.1 Number of Tests: 3-5

3.2 Description: Head cooling will be separated from the cylinder wall cooling system and a variety of means of cooling the cylinder head will be tried, such as nitrogen, hydrogen, boiling water, or Dowtherm "A". The optimum head temperature for vacuum operation will be determined. An uncooled (radiation cooled) head with ceramic insulation will be checked.

3.3 Estimated Running Time: 3 hours

In addition, more exhaust samples will be taken, and the flow of oil through the crankcase at high engine speeds will be studied by the use of transparent plastic valve covers on a motoring engine.